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Patentanmeldung Nr. Patent application No. Demande de brevet n°

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R C van Dijk

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Polyganics B.V.
L.J. Zielstraweg 1
9713 GX Groningen
PAYS-BAS

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Biodegradable phase separated segmented/block co-polyesters

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Title: Biodegradable phase separated segmented/block co-polyesters

The invention is directed to biodegradable, thermoplastic, phase separated segmented/block copolymers. The copolymers of the present invention find use in various biomedical as well as pharmaceutical applications.

Generally, thermoplastic phase separated co-polymers consist of a low glass transition temperature (Tg), flexible 'soft' segment and a high Tg (or Tm: melting temperature), glassy or (semi)crystalline 'hard' segment which are incompatible or only partially compatible.

Examples of phase separated segmented/block copolymers are found *e.g.* in US-A-6 255 408, US-A-5 554 170, US-A-5 066 772, US-A-5 236 444, US-A-5 133 739 and US-A-4 429 080. These known materials are bioresorbable co-polyesters wherein the hard blocks are predominantly build of crystalline poly-glycolide and/or poly-lactide. Glycolide rich polyesters are especially suitable for fast resorbable biomedical articles such as mono- or multi filament sutures; lactide rich polyesters are used in more slowly resorbing medical applications, such as nerve guides, nerve graft and many other products. However, the high melting point of the poly-glycolide or poly-L-lactide rich blocks requires very high polymerisation and processing temperatures (about 200 °C), which may result in unwanted degradation behavior and/or trans-esterification. Furthermore, the poly-glycolide rich polyesters are unsuitable for applications for which a slow resorption is needed.

As an alternative to polyglycolide rich polyesters, poly-L-lactide rich copolyesters have been suggested as materials which have a higher resorption time and very good mechanical properties as a result of the crystalline segments. However, the use of a semi-crystalline random copolymer of L-lactide and ε-caprolactone (50/50) for bridging of peripheral nerve defects and of highly crystalline poly-L-lactide as bone plates have caused some severe problems in the past. Mild to severe foreign body reactions were observed after 2 to 3 years of implantation, respectively, due to the presence of long-lasting

biomaterial fragments. (Den Dunnen *et al.* (Microsurgery 14 (1993) 508-515) ; Rozema et.al. In : P.J. Doherty, R.L. Williams, D.F. Williams, eds. "Biomaterial-Tissue interfaces. Advances in biomaterials" 10 Amsterdam, Elsevier Science Publishers B.V. (1992) 349-355).It is an object of the present invention to provide a new biodegradable, thermoplastic, phase separated segmented/block copolymer, which does not suffer from the above-mentioned disadvantages and thus opens possibilities for new medical applications. The copolymer of the invention is characterized by good mechanical properties, in particular good tensile strength, elongation and elastic properties.

It has been found that this can be obtained by a biodegradable, phase separated copolymer, comprising blocks or segments of a soft prepolymer (A) having a Tg lower than 37°C; and blocks or segments of a hard polyester prepolymer (B) having a phase transition temperature of 40-100°C.

The term "phase-separated", as used herein, refers to a system, in particular a copolymer, of two or more different prepolymers, which are incompatible with each other. Thus the prepolymers do not form a mixture when combined, neither when combined as a physical mixture of the prepolymers, nor when the prepolymers are combined in a single chemical species as "chemical mixture", *viz.* as copolymer.

The term "prepolymer" refers to the chemical units or building blocks making up the copolymer of the present invention. Each prepolymer may be obtained by polymerization of suitable monomers, which monomers thus are the building blocks of each prepolymer. The desired properties of the prepolymers and, by consequence, of the copolymer of the present invention may be controlled by choosing a prepolymer of a suitable composition and molecular weight (in particular Mn), such that the required Tm or Tg is obtained.

The phase-separated quality of the copolymers of the present invention is reflected in the profile of the glass transition temperature (Tg) or melting temperature (Tm). Whereas a single prepolymer is usually

characterized by a single phase transition (Tg or Tm), the phase-separated copolymers are characterized by at least two phase transitions, each of which is related (but not necessarily identical) to the corresponding Tg or Tm values of the prepolymers which are comprised in the copolymer. Prepolymers which would form an (ideal) mixture or blend would result in a copolymer having a single Tg or Tm. The glass transition temperature, Tg, is determined by taking the midpoint of the specific heatjump, as may be measured *e.g.* by differential scanning calorimetry (DSC). The melting temperature, Tm, is the peak maximum of the melting peak, as is schematically illustrated in Fig.1, in which curve 1 shows the heat flow endotherm for a copolymer characterized by a Tg and a Tm. Curve 2 shows a copolymer having two Tg's.

As defined herein, values of Tg and Tm of a certain prepolymer reflect the values as measured on the copolymer. For instance, the Tg of the soft segment is the Tg measured on the copolymer. In case of complete immiscibility of the prepolymers, the Tg of the copolymer is governed solely by the Tg of the amorphous, "soft" prepolymer. In most cases, however, the composition of the hard and the soft segments of the copolymer is not exactly the same as the composition of the prepolymers from which the copolymer is prepared. Part of the original hard prepolymer will mix with the soft prepolymer and thus become part of the soft phase. The Tg value of the soft segment is than different of that of the prepolymer used. The extent of miscibility (and therefore the deviation of Tg and/or Tm from those of the corresponding pre-polymers) is dependent on the pre-polymer ratio and -segment length in the copolymer.

The material of the present invention can be processed at relatively low temperatures, thus avoiding transesterification and other side-reactions reactions, which cause the generation of undesired degradation and other by-products.

Biodegradable phase separated polyesters or polyester-carbonates of this invention are a promising group of biomaterials and can be used in

various biomedical applications since they exhibit good mechanical, elastic and processing properties. Furthermore, they can be used in pharmaceutical applications, *e.g.* for drug delivery. Their mechanical and degradation properties can easily be tuned by changing the type of monomers of the soft and hard segment and their chain length and –ratio. Furthermore, the thermal properties are low enough for processing the polymer in the melt and high enough to be used as a biomedical implant. The monomer ratio and-distribution of the copolymer can be easily controlled by varying the polymerization conditions.

A crystalline or glassy hard segment is desired to obtain elastomeric and tough materials. A low Tg or low melting soft segment is necessary to obtain high elasticity. The phase separated property of the copolymers of the invention is essential, since it enables that the hard segments may contribute to the mechanical strength, whereas the soft segments provide for the desired elastic properties.

A prerequisite of the biomedical phase separated segmented co-polyester is that the melting point or high Tg value (*i.e.*, phase transition temperature) of the polyester hard segment is larger than 40°C: the phase separated morphology must also be present at body temperature and environment in order to retain the initial mechanical properties after implantation. An important class of segmented co-polyesters with a good phase separation are those based on crystalline poly-ε-caprolactone hard segments. For example, a different approach to obtain semi-crystallinity without the presence of long L-lactide sequences as in the previously mentioned copolymer is the use of a phase separated copolymer of dl-lactide and ε-caprolactone with a monomer ratio that results in crystallization of the caprolactone part of the copolymer. Since the rate of degradation of poly-ε-caprolactone is low, especially in the crystalline phase, it is also a good way to lower the degradation rate of the copolymer. In this way, biocompatible biomedical articles of ε-caprolactone rich copolymers can be applied in situations when a

slow resorbing rate is desired without the use of a major L-lactide content. The low melting temperature of the crystalline phase (50-60°C) makes this copolymer very easy to process.

This crystalline phase will have a melting point that is similar to or only a little lower than that of the high molecular weight homopolymer of ε-caprolactone (60-65 °C). To obtain a thermoplastic elastomer with a modulus that is not too high, the content of this hard phase can be rather low (either dispersed or in a co-continuous system with the rubber phase).

The desired phase separated morphology (reflected by one melting point and at least one low Tg value or at least two separated Tg values) may be obtained by varying the composition, *e.g.* by choosing the number average molecular weight, Mn, of the A and B blocks. It is also possible to influence the phase separated morphology by varying the A/B ratio.

Although random copolymers of lactide and ε-caprolactone with a crystallisable ε-caprolactone content have been prepared in the past, the phase separation is not as good as in the phase separated segmented/block co-polymers of this invention. This is proved by the much lower melting temperature of the crystalline ε-caprolactone segment, lower melting enthalpies (ΔH) and lower values of Tg (more amorphous ε-caprolactone present in the soft phase) of the random copolymers (see *e.g.* Hiljainen-Vainio *et al.*, Lemmouchi *et al.*, US-A-4 643 734).

General polymer structures

The segmented or block copolymers of this invention consist of a soft segment or block which is preferably completely amorphous at room temperature, hydrolysable and with a Tg or melting point below 37 °C or preferably below 25 °C (phase A) and a hard segment or block, consisting of a biodegradable crystalline or semi-crystalline polyester or glassy polyester with a high Tg with a phase transition larger than 40 °C but smaller than 100 °C (phase B). The "hard" and "soft" phases are incompatible or only partially

compatible. A block copolymer according to the invention consists of two or more blocks or long structures of repeat units with e.g. the general form AB, ABA, BAB, ABABA; multi-block or segmented copolymers have a structure (ab)n, (aba)n, (bab)n or a random distribution of segments (ab)r. In general, the a and b segment lengths are smaller than the A and B blocks in the block-copolymers. The pre-polymers of which the a and b segments are formed in (ab)r and (ab)n are linked by the bifunctional chain-extender. In case a diisocyanate is used and the prepolymer contains hydroxyl end-groups, the linking units are urethane groups. In (aba)n and (bab)n the aba and bab prepolymers can be linked by a diisocyanate. Multi-block copolymers with alternating a and b segments (ab)n can also be prepared by a reaction of a di-carboxylic acid terminated pre-polymer with a diol-terminated pre-polymer, using a coupling agent such as DCC (dicyclohexyl carbodiimide). This type of co-polyesters does not contain urethane groups.

The term "multi-block" copolymers e.g. (ab)n refers to copolymers with alternating segments of short length. These include copolymers with the general structure (aba)n and (bab)n.

"Randomly segmented" copolymers refer to copolymers that have a random distribution (i.e. not alternating) of the segments a and b.

Polymerisation method and conditions:

Segmented/block co-polymers with structure (ab)r can be made by chain-extending a mixture of the pre-polymers, containing the hard- and the soft segment forming monomers of segments a and b, in the desired ratio with an equivalent amount of a di-functional, preferably an aliphatic molecule such as 1,4-butanediisocyanate (BDI). Preferably, the reaction is carried out in the bulk at a temperature at which the pre-polymer mixture is a melt and which is at least 20 °C higher than the highest phase transition temperature of the pre-polymer. Polymerisation takes place at this temperature for a time long enough to obtain an intrinsic viscosity of the copolymer of about 1 dl/g. Solid

state post polymerisation at room temperature may increase the molecular weight to an intrinsic viscosity up to 4 dl/g. The specific polymerisation time and temperatures for this bulk polymerisation are given in the examples below, but may be different for other pre-polymer combinations. This bulk polymerisation method is also applicable to segmented co-polymers with structures (aba)n and (bab)n. The low polymerisation temperature and short polymerisation time will prevent from trans-esterification so that the phase separated morphology is obtained. On the contrary, high molecular weight random copolymers have to be prepared at higher temperatures (> 100 °C) and for a much longer time to obtain a full incorporation of all the monomers. During that time trans-esterification reactions will occur and a more random monomer distribution is obtained.

The alternating multi block-copolymers (ab)n are preferably formed by reacting (end-capping) one of the pre-polymers with at least two equivalents of a di-functional chain-extender, removing the excess of chain-extender and than add the other pre-polymer in about 1:1 ratio. The polymer can be made either in bulk or in solution. An alternative polymerisation method in solution, is the use of a coupling agent such as DCC (dicyclohexyl carbodiimide) in the condensation of di-acid and diol terminated pre-polymers.

The materials obtained by chain-extending in the bulk can also be produced *in situ* in an extruder.

The segmented copolymers of structures (ab)r or (aba)n or (bab)n can also be made in solution. The pre-polymer(s) are dissolved in an inert organic solvent and the chain-extender is added dropwise or in solution. The polymerisation temperature can be the same or even lower than the highest phase transition temperature of the pre-polymers.

Block-copolymers ABA, BAB, ABABA and pre-polymers of which the multi-block copolymers with structures (aba)n or (bab)n can be prepared, are generally made by addition of the monomer(s) of which the outer block will be formed to a pre-polymer with monomers that form the inner block. These

methods are known in the art. Since the aba and bab pre-polymers are build of relatively short segments, the pre-polymer can subsequently be chain-extended with a di-functional molecule by the method described above.

The AB block copolymer can be prepared by adding the monomers forming block B to a living polymer chain of block A and vice versa. The preferred method will be the one that gives the lowest degree of trans-esterification: the segments or blocks in the final copolymer should have a monomer sequence equal or close to that of the pre-polymers. This results in a good phase separation of the soft and hard segments. Tri-block BAB polymerisation may suitably be initiated by a di-functional (co)polymer A or a mixture of (co)polymer A and a polyether.

If the chain-extender is a difunctional, aliphatic molecule and the pre-polymers are linear, a linear co-polymer is made; if one of the reactants (either the chain-extender or at least one of the pre-polymers) or both have more than two functional groups, cross-linked structures are obtained. Preferably, the chain-extender is an aliphatic di-isocyanate such as 1,4-butanediisocyanate. Also other aliphatic chain-extenders can be used as long as they don't contribute significantly to the mechanical and thermal properties.

The combination of hard- and soft phase forming pre-polymers or monomers is chosen in such a way to obtain a phase separated segmented or block co-polyester or polyester- carbonate with the desirable degradation, mechanical and thermal properties. Since the two phases are chemically linked, the border of the phases is partly mixed and will result in good mechanical properties of the copolymer, even when the hard and soft segment are completely incompatible.

Pre-polymers: composition and method of preparation

The amorphous soft phase in the co-polymer is formed by pre-polymers (one or more) (A) or blocks consisting of cyclic monomers such as

glycolide, lactide (racemic, meso, L-lactide or D-Lactide or DL-Lactide other than racemic), ε-caprolactone, δ-valerolactone, trimethylenecarbonate, 1,4 dioxane-2-one and combinations thereof. To fulfill to the requirement of a Tg below 37 °C of the soft segment, prepolymer (A) preferably does not comprise the monomers lactide and/or glycolide without the presence of any of the other cyclic co-monomers listed in the previous sentence.

This pre-polymer or pre-polymer mixture can also contain polyethers such as polyethyleneglycol (PEG). The polyether can be part of the pre-polymer by using it as an initiator or it can be mixed with the polyester- or polyester-carbonate pre-polymers. Furthermore, the soft phase can be based on polyesters of (mixtures of) lactic acid, glycolic acid, glutaric, adipic, succinic or sebacic acid and ethyleneglycol, 1,4-butanediol or 1,6-hexanediol. Prepolymer (A) may *e.g.* be prepared by ring-opening polymerisation. Thus a prepolymer (A) may be a co-polyester(-carbonate) prepared by ring-opening polymerisation initiated by a diol or di-acid compound, preferably having a random monomer distribution. The diol compound is preferably an aliphatic diol or a low molecular weight polyethyleneglycol.

The hard phase can be formed by blocks or segments (B) containing any hydrolysable, biocompatible polyester with a phase transition between 40 °C and 100 °C. Examples of the hard phase forming pre-polymers are those containing a crystallisable amount of ε-caprolactone or δ-valerolactone or a pre-polymer or block based on amorphous dl-lactide or lactide/glycolide.

Pre-polymers containing aromatic groups are generally not suitable for the hard pre-polymer, because they have a transition temperature that is too high (> 100 °C). Furthermore, the processing temperature is high, the solubility in common organic solvents is generally too low and pre-polymers containing aromatic groups may give rise to undesired degradation products. Typically pre-polymer (B) has a Mn of larger than 1000, preferably larger than 2000, more preferably larger than 3000, which numbers particularly hold for the case where prepolymer (B) is poly-ε-caprolactone. In general Mn of

prepolymer (B) will be less than 500 000. The content of prepolymer (B) in the copolymer is preferably 10-90 wt.%, more preferably 25-70 wt%, most preferably 30-50 wt.% (particularly for poly-ε-caprolactone).

The L/D ratio of the lactide used in poly-dl-lactide blocks or segments may vary between 85/15 and 15/85, a ratio that gives an amorphous homo-polymer. Furthermore, addition of 15% of the other isomer (L or D) increases the Tg of the poly-lactide. A minor amount of any other of the above mentioned monomers that build the soft phase may also be present in the hard phase forming pre-polymer or block.

The pre-polymers will preferably be linear and random (co)polyesters or polyester-carbonates with reactive end-groups. These end-groups may be hydroxyl or carboxyl. It is preferred to have a dihydroxy terminated co-polyester, but hydroxy-carboxyl or dicarboxyl terminated polyesters can also be used. In case the polyester has to be linear, it can be prepared with a di-functional component (diol) as a starter, but in case a three or higher functional polyol is used star shaped polyesters may be obtained. The diol can be an aliphatic diol or a low molecular weight polyether.

The pre-polymer synthesis is preferably carried out in the presence of a catalyst. A suitable catalyst is $Sn(Oct)_2$ with M/I= 5000-30000. It is also possible to carry out the synthesis without a catalyst.

The conditions for preparing the polyesters are those known in the art.

The copolymers of the present invention are generally linear. However, it is also possible to prepare the copolymers in a branched or cross-linked form. These non-linear copolymers of the present invention may be obtained by using a tri- (or more) functional chain extender, such as tri-isocyanate. Branched copolymers may show improved creep characteristics.

Cross-linked copolymers are generally not preferred, since these copolymers are not easy to process.

Pre-polymer length and ratio of pre-polymers in segmented co-polyesters.

In case of a crystallisable hard segment, the length (number average molecular weight, Mn) of the pre-polymer must be large enough to be able to crystallise in the copolymer. E.g. poly-ε-caprolactone (PCL) hard segment forming pre-polymer is preferably larger than 1000, more preferably larger than 2000, most preferably larger than 3000. A larger PCL pre-polymer length results in a phase separated morphology at a lower hard segment content, as will be shown in the results. The pre-polymer ratio at which phase separation is observed is therefore dependent on the pre-polymer lengths. In general, the lengths of the pre-polymers that form the soft and hard segment within a copolymer must have a value at which a phase separated morphology is observed, the extent of phase separation (compatibility) being favorable for the desired properties of the biomedical device.

The length of the soft segment forming pre-polymer can be 1000 (Mn), preferably 2000 or as large as is necessary to obtain a good phase separated morphology and good mechanical and thermal properties of the resulting copolymer. The pre-polymer length must be low enough to be miscible with the chain-extender at the polymerisation temperature, typically this means that Mn is lower than 6000. This is also the case in pre-polymers with structures aba and bab. The length of the outer segment is therefore dependent on the type of monomers used for both inner and outer segments.

Generally, a hard segment content in the range of 10-90 wt.%, preferably of 25- 60%, results in flexible, thermoplastic materials with good mechanical properties at the temperature of application (*viz.* about 37°C for medical applications).

Pre-polymer length and ratio of pre-polymers in block co-polyesters

Generally, the block lengths must be large enough to phase separate and to result in a copolymer with a molecular weight which is large enough to obtain the desired mechanical, degradation and processing properties. The molecular weight (Mn) of the block-copolymer is preferably 15000-600000 (at a polydispersity of about 2), more preferably 40000-300000, most preferably 90000-200000. The requirements for the preferred hard and soft segment ratio will be similar as those for the segmented copolymers.

Polymer properties and applications

Very high molecular weights of the block/segmented copolymers are not necessary to obtain good mechanical properties. With an intrinsic viscosity of the copolymer of about 0.8 dl/g the initial mechanical properties will be sufficient for the production of medical devices. High intrinsic viscosities are undesirable, because the polymer will be difficult to process. Typically, the intrinsic viscosity is larger than 0.1 dl/g and less than 10 dl/g. Preferably, the intrinsic viscosities lie between 1-4 dl/g.

The block/segmented copolymers can be formed into surgical articles using any known technique such as, for example, extrusion, molding, solvent casting and freeze drying. The latter technique is used to form porous materials. Porosity can be tuned by addition of co-solvents, non-solvents and/or leachables. Copolymers can be processed (either solid or porous) as films, sheets, tubes, membranes, meshes, fibers, plugs and other articles. Products can be either solid, hollow or (micro)porous. A wide range of surgical articles can be manufactured for applications in for example wound care, skin recovery, nerve regeneration, vascular prostheses, drug delivery, meniscus reconstruction, tissue engineering, coating of surgical devices, ligament and tendon regeneration, dental and orthopedic repair. The copolymers can be used

alone or can be blended and/or co-extruded with other absorbable or non-absorbable polymers.

Furthermore, they can be used in pharmaceutical applications, e.g. for drug delivery, *e.g.* in the form of microspheres or membranes.

As will be illustrated in the examples below, the materials of the present invention have improved properties, including thermal, mechanical, processing compared to copolymers described in the prior art.

Brief description of the drawings:

Figure 1 shows the heat flow endotherms of two types of phase separated copolymers, curve 1 being characterised by a Tg and a Tm of a copolymer, curve 2 by 2 Tg's.

Figure 2 shows the relation between the glass transition temperature (Tg1 of first DSC run, Tg2 of second DSC run) and the ε-caprolactone content of co-polyesters with different PCL pre-polymer lengths and of random copolymers of DL-Lactide and ε-caprolactone: ◆ (closed diamonds): Tg1 of co-polyester with PCL2000 pre-polymer; ◇ (open diamond): Tg2 of co-polyester with PCL2000 pre-polymer; ■ (closed square): Tg1 of co-polyester with PCL3000 pre-polymer; □ (open square): Tg2 of co-polyester with PCL3000 pre-polymer; ● (closed circle): Tg1 of co-polyester with PCL4000 pre-polymer; ○(open circle): Tg2 of co-polyester with PCL4000 pre-polymer;▲ (closed triangle): Tg1 of random co-polyester; △ (open triangle): Tg2 of random co-polyester; *: Tg2 of co-polyester with lactide-ε-caprolactone pre-polymer with Mn=2000.

Figure 3 shows the relation between the melting temperature (peak maximum, Tm) of the first DSC run and the ε-caprolactone content of co-polyesters with different PCL pre-polymer lengths and of random copolymers of DL-Lactide and ε-caprolactone: ◆ (closed diamonds): Tm1 of co-polyester with PCL2000 pre-polymer; ■ (closed square): Tm1 of co-polyester with

PCL3000 pre-polymer; ▲ (closed triangle): Tm1 of random co-polyester; ● (closed circle): Tm1 of co-polyester with PCL4000 pre-polymer.

Figure 4 shows the relation between the melting enthalpy (ΔH) of the first DSC run and the ε-caprolactone content of co-polyesters with different PCL pre-polymer lengths and of random copolymers of DL-Lactide and ε-caprolactone: ◆ (closed diamonds): ΔH1 of co-polyester with PCL2000 pre-polymer; ■ (closed square): ΔH1 of co-polyester with PCL3000 pre-polymer; ▲ (closed triangle): ΔH1 of random co-polyester; ● (closed circle): ΔH1 of co-polyester with PCL4000 pre-polymer.

Figure 5 shows the relation between the melting enthalpy (ΔH) of the first DSC run and the average caprolactone sequence length, $\bar{L}_{Cap}$, of co-polyesters with different PCL pre-polymer lengths and of random copolymers of DL-Lactide and ε-caprolactone: ◆ (closed diamonds): ΔH1 of co-polyester with PCL2000 pre-polymer; ■ (closed square): ΔH1 of co-polyester with PCL3000 pre-polymer; ▲ (closed triangle): ΔH1 of random co-polyester; ● (closed circle): ΔH1 of co-polyester with PCL4000 pre-polymer; *: ΔH1 of co-polyester with lactide-ε-caprolactone pre-polymer with Mn=2000.

Figure 6 shows the relation between the average caprolactone sequence length, $\bar{L}_{Cap}$ and ε-caprolactone content of co-polyesters with different PCL pre-polymer lengths and of random copolymers of DL-Lactide and ε-caprolactone: ◆ (closed diamonds): $\bar{L}_{Cap}$ of co-polyester with PCL2000 pre-polymer; ■ (closed square): $\bar{L}_{Cap}$ of co-polyester with PCL3000 pre-polymer; ● (closed circle): $\bar{L}_{Cap}$ of co-polyester with PCL4000 pre-polymer; ▲ (closed triangle): $\bar{L}_{Cap}$ of random co-polyester. (closed circle): *: $\bar{L}_{Cap}$ of co-polyester with lactide-ε-caprolactone pre-polymer with Mn=2000.

Figure 7 shows the stress-strain behavior of the segmented co-polyesters with the PCL3000 pre-polymer with different PCL3000 content.

Figure 8 shows the relation between the elastic modulus (*E*) and the ε-caprolactone content of co-polyesters with different PCL pre-polymer

lengths and of random copolymers of DL-Lactide and ε-caprolactone: ◆ (closed diamonds): E of co-polyester with PCL2000 pre-polymer; ■ (closed square): E of co-polyester with PCL3000 pre-polymer; ▲ (closed triangle): E of random co-polyester.

EXAMPLES

Analysis Methods:

The following analysis methods were used in all examples, unless indicated otherwise.

The intrinsic viscosity was measured in chloroform at 25 °C using an Ubbelohde viscometer (according to ISO standard 1628-1).

Molecular weights were determined by Gel Permeation Chromatography at 30°C using a Spectra Physics instrument equipped with 2 PL-Mixed -C columns (Polymer Labs), operating with tetrahydrofuran as eluent and with a Shodex RI-71 refractometer. Samples were dissolved in THF (1 mg ml^{-1}), the injection volume was 100 μl and the flow rate 1 ml min^{-1} Calibration curves were obtained by polystyrene standards.

Pre-polymer and copolymer composition, monomer distribution (average sequence length, $\bar{L}_{Lac}$ and $\bar{L}_{Cap}$) were determined using ^{1}H-NMR at 300 MHz in solutions in deuterated chloroform.

Thermal properties were determined using a Perkin-Elmer DSC-7, 5-10 mg samples being heated at a rate of 10 °C per minute, cooled down at a rate of 10 °C per minute, hold for 1 minute at -90 °C and heated again at a rate of 10 °C per minute. Tg and Tm were determined from the resulting DSC curves.

The stress strain behavior was determined on an Instron 4301 tensile tester. Thin films (0.25 mm) were measured at room temperature at a cross-head speed of 10 mm/minute. The ultimate tensile strength, the stress at 250% strain, the elongation at break and the initial modulus were determined from these measurements.

Films were prepared by evaporating a solution of the co-polyester in chloroform in a petri-dish during 7 days at room temperature.

Polymer properties are given in Tables 1-5.

The following notation is used to indicate the composition of the copolymers: e.g. the columns cap2000 and dl-lac/cap2000 in Table 1 give the ratio of the two pre-polymers (% w/w) (cap2000 is PCL pre-polymer with Mn=2000; dl-lac/cap2000 is DL-Lactide-ε-caprolactone pre-polymer with Mn=2000). The first column gives the molar co-monomer composition of the resulting copolymer: e.g. P(CL-DLLA) 80-20 contains 80 mol% ε-caprolactone (the total amount of ε-caprolactone in the two pre-polymers) and 20 mol% of dl-lactide.

Examples prepolymers:

Example 1: DL-Lactide-ε-caprolactone prepolymer (Mn=2000)

32.82 grams (0.231 mol) DL-Lactide (Purac, the Netherlands) was introduced into a three-necked bottle under nitrogen atmosphere and was dried in vacuum at 45 °C for at least 8 hours. ε-Caprolactone (Acros, Belgium) is dried over CaH_2 and distilled under reduced pressure in a nitrogen atmosphere. 26.32 grams (0.231 mol) ε-caprolactone was added under a nitrogen flow . 2.68 grams (29.7 mmol) of 1,4-butanediol (Acros, distilled from 4 Å molecular sieves after drying for 8 hours) was added. 24.8 mg stannous octoate (Sigma Corp) was added (M/I=8000). The mixture was magnetically stirred and reacted at 130 °C during 162 hours. ^{1}H-NMR showed complete monomer conversion. The lactide:ε-caprolactone ratio in the pre-polymer was 48.4:51.6 (calculated by ^{1}H-NMR). The calculated molecular weight (Mn) was 2080 and was confirmed by end-group analysis with ^{1}H-NMR.

Example 2: ε-Caprolactone prepolymer (Mn=2000)

193.98 grams (1.70 mol) ε-Caprolactone (see example 1 for purification) was introduced into a three-necked bottle under nitrogen

atmosphere. 8.74 grams (97.0 mmol) of 1,4-butanediol (see example 1 for purification) was added. 78.7 mg stannous octoate (Sigma Corp) was added (M/I=9130). The mixture was magnetically stirred and reacted at 130 °C during 160 hours. ^{1}H-NMR showed complete monomer conversion. The calculated molecular weight (Mn) was 2090 and was confirmed by end-group analysis with ^{1}H-NMR

Example 3: ε-Caprolactone prepolymer (Mn=3000)

A pre-polymer with Mn = 3000 was prepared in the same way as described in example 2. The calculated molecular weight (Mn) was 3160 and was confirmed by end-group analysis with ^{1}H-NMR

Example 4: General polymerisation method of segmented co-polyesters with randomly distributed segments: P(CL-DLLA)

The PCL pre-polymer (2000, 3000 or 4000) and dl-lactide-ε-caprolactone pre-polymer are pre-heated until 70 °C until they become more liquid. The appropriate amounts of both pre-polymers are weighted into a glass ampoule supplied with nitrogen inlet and a mechanical stirrer. 1 equivalent of 1,4-butanediisocyanate (Bayer, distilled at reduced pressure) is added. The contents of the ampoule are quickly heated to 65 °C and then stirred mechanically for 15 minutes. As the mixture becomes viscous, the temperature is increased to 80 °C. Stirring is stopped when the mixture becomes too viscous (between ½ -1½ hour) and the heating is continued for a maximum of 24 hours.

De ampoule is cooled to room temperature and post-polymerisation continues for 48 hrs. Then, the contents are isolated by dissolving the polymer in chloroform. The solution is filtered and poured into a petri-dish. The solvent is evaporated and after that the polymer film is dried in a vacuüm oven at 40 °C.

The polymer is stored in a sealed package at room temperature for at least 1 week before characterization takes place (thermal and mechanical

properties and intrinsic viscosity). Polymer composition (average sequence length, $\bar{L}_{Lac}$ and $\bar{L}_{Cap}$) is determined by ^{1}H-NMR.

Example 5: Synthesis of random co-polyesters:

Random copolymers were synthesized by a ring opening polymerization in the bulk initiated by stannous octoate. DL-Lactide (Purac, the Netherlands) and ε-Caprolactone (Acros, Belgium; dried over CaH_2 and distilled under reduced pressure in a nitrogen atmosphere) were charged into a clean, dry glass ampoule with nitrogen inlet. Stannous octoate was added (see Table 3) and the ampoule was placed in an oil bath at 120 °C. The contents were kept under nitrogen atmosphere. The ampoules were heated for 5 days and were then cooled to room temperature. A sample of the polymer was taken for NMR measurements. The polymers were dissolved in chloroform and precipitated in ethanol (96%). Films for thermal and mechanical analysis were made from the purified copolymers. Intrinsic viscosities were measured from the purified copolymers.

Example 6: Preparation of nerve guides.

Copolymers prepared according to the method in Example 4 with various ε-caprolactone/lactide ratios and with both PCL2000 and PCL3000 pre-polymers have been used for preparation of nerve guides. To this end, for each copolymer a polymer solution in chloroform was dip-coated on mandrels with various diameters. After dipping, the mandrel was placed horizontally and the solvent was allowed to evaporate during 5 minutes while rotating. This procedure was repeated until the desired wall thickness was obtained. The mandrel with the copolymer layer was placed first in ethanol and after that in distilled water. The tubes were removed from the mandrel and were cut into the appropriate lengths. They were placed in ethanol, followed by vacuum drying at 40°C in order to remove monomer- and low molecular weight residues and organic solvents.

Example 7: Preparation of microspheres

A copolymer (1 gram) prepared according to the method in Example 4 containing 39.3 % (w/w) of PCL3000 prepolymer is dissolved in 50 ml of dichloromethane. A 3% polyvinylalcohol (PVA Mw=22.000) solution in 800 ml water is made. The solutions are filtered. The PVA solution is stirred at a rate of 200-800 rpm during the whole process. The polymer solution is added to the PVA solution. The solutions are stirred during 1.5 hours while evaporating the dichloromethane at reduced pressure. The stirring is stopped and the microspheres are collected from the aqueous phase, after which they are washed several times with water. Finally, the microspheres are dried by vacuüm or freeze-drying. According to this method, hollow microspheres with solid outer layer ($d_{50} \sim 25\mu m$) can be obtained. By slight modification of the process, also solid and porous particles and particles with a smaller or larger size can be prepared.

Table 1: *Properties of segmented co-polyesters with PCL 2000 pre-polymer*

P(CL-DLLA) (mol%)	Composition (%w/w)		[η]	$\bar{L}_{Cap}$	$\bar{L}_{Lac}$	Tg_1 (°C)	Tg_2 (°C)	Tm_1 (°C)	Tm_2 (°C)	ΔH_1 (J/g)	ΔH_2 (J/g)
	Cap2000	dl-lac/cap 2000									
63.6-36.4	23.4	76.6	3.62	3.8	4.3	-23.6	-25.2	37.0	-	7.6	-
72.0-28.0	41.0	59.0	2.25	5.5	4.3	-24.4	-34.5	48.4	-	25.0	-
74.6-25.4	46.6	53.4	1.19	6.1	4.2	-23.7	-36.6	53.3	41.7	34.3	1.9
79.5-20.5	56.8	43.2	1.30	8.3	4.3	-29.5	-41.7	54.4	38.7	39.5	20.7

Table 2: *Properties of segmented co-polyesters with PCL 3000 pre-polymer*

P(CL-DLLA) (mol%)	composition (% w/w)		[η]	$\bar{L}_{Cap}$	$\bar{L}_{Lac}$	Tg_1 (°C)	Tg_2 (°C)	Tm_1 (°C)	Tm_2 (°C)	ΔH_1 (J/g)	ΔH_2 (J/g)
	Cap3000	dl-lac/cap 2000									
67.7-32.3	33.3	66.7	1.99	4.0	3.8	-16.8	-29.6	49.0	-	26.7	-
70.6-29.4	39.3	60.7	1.27	4.8	4.0	-17.1	-34.3	57.7	45.4	32.0	1.82
75.3-24.7	48.9	51.1	1.31	6.2	4.1	-20.7	-40.0	58.4	45.7	39.2	18.7
76.5-23.5	51.4	48.6	1.13	6.4	3.9	-22.1	-38.9	57.4	45.7	42.1	21.3
79.2-20.8	57.0	43.0	1.61	7.6	4.0	-24.1	-42.6	53.7	45.0	44.3	26.2
51.7-48.3	-	100	-	2.4	4.1	-13.9	-11.3	-	-	-	-
100-0 *)	-	-	-	-	-	-58.1	-61.0	64.0	59.0	81.7	63.0

*): (Mn=80000)

Table 3: *Properties of segmented co-polyesters with PCL 4000 pre-polymer*

P(CL-DLLA) (mol%)	composition (% w/w)		[η]	$\bar{L}_{Cap}$	$\bar{L}_{Lac}$	Tg_1 (°C)	Tg_2 (°C)	Tm_1 (°C)	Tm_2 (°C)	ΔH_1 (J/g)	ΔH_2 (J/g)
	Cap4000	dl-lac/cap 2000									
62.2-37.8	18.9	83.1	2.35	3.3	4.0	-20.8	-23.9	38.7	-	8.8	-
67.4-32.6	28.4	71.6	1.00	4.1	4.0	-17.7	-31.1	56.9	46.2	25.1	4.2

Table 4: *Properties of random co-polyesters*

P(CL-DLLA) (mol%)	M/I	[η]	$\bar{L}_{Cap}$	$\bar{L}_{Lac}$	Tg_1 (°C)	Tg_2 (°C)	Tm_1 (°C)	Tm_2 (°C)	ΔH_1 (J/g)	ΔH_2 (J/g)
74.5-25.5	7200	3.12	4.0	2.9	-39.3	-38.9	42.4	-	9.0	-
77.5-22.5	8500	3.78	7.1	4.1	-37.4	-46.9	43.7	39.7	28.5	7.1
80.2-19.8	4650	2.18	5.2	2.6	-37.3	-42.7	42.0	-	20.2	-

Table 5: *Molecular weights of phase separated, segmented co-polyesters measured by GPC*

P(CL-DLLA) (mol%)	PCL length	[η]	Mw (·10^{-3})	MN (·10^{-3})	D
63.6-36.4	2000	3.62	234.0	117.3	2.0
74.6-25.4	2000	2.08	287.0	89.0	3.23
67.7-32.3	3000	1.99	171.9	83.3	2.07
75.3-24.7	3000	1.31	287.9	115.9	2.50

Results and discussion

Summary:

Segmented co-polyesters build of a DL-lactide-ε-caprolactone soft segment (with Mn 2000) and of a PCL hard segment (with Mn 3000 or Mn 4000) and with a hard segment content of 33-57 % and 28 % (w/w), respectively, are flexible, thermoplastic elastomers with good mechanical and thermal properties. This type of material seems very promising for being used for nerve guides capable of bridging nerve defects larger than 2 cm.

As a reference material, random copolymers of D,L-Lactide and ε-caprolactone with similar monomer compositions as the segmented copolymers have been prepared. The lower degree of phase separation and the lower melting point of the crystalline phase makes them less applicable as polymers for biomedical devices. These differences are caused by a different monomer distribution: in a block-copolymer such as the phase separated lactide/ε-caprolactone based co-polyester, the average sequence length of the monomers will be longer and the sequence length distribution will be much smaller than in a 'random' copolymer. The average monomer sequence length will affect the thermal- and mechanical properties of the copolymer.

Results:

Phase separated segmented co-polyesters with structure (ab)r consisting of a poly-ε-caprolactone hard phase and a poly(dl-lactide-ε-

caprolactone) soft phase have been prepared with various ratio's of dl-lactide and ε-caprolactone. A non-random distribution of lactide and ε-caprolactone is obtained: a small part of the poly(ε-caprolactone) prepolymer is amorphous and is present in the amorphous poly(lactide-ε-caprolactone) phase; the major part of the poly-ε-caprolactone is present as the crystalline hard phase. The degree of phase-mixing and the polymer properties are dependent on the pre-polymer chain length and -ratio.

Phase separation occurs above a certain threshold of the hard phase content. The content at which the hard phase is formed (crystallisation) is related to the molecular weight (chain length) of the pre-polymer(s). Segmented polyesters based on PCL (poly-ε-caprolactone) hard segments and lactide-ε-caprolactone soft segments and with Mn=2000 of the soft segment forming pre-polymer show a good phase separation with a pre-polymer content of 40-45 % of the PCL hard segment forming phase with Mn=2000, 33% of a pre-polymer with Mn=3000, and 28% of a pre-polymer with Mn=4000, respectively. The longer PCL segment results in a better phase separation beginning at lower concentration. The effects of the composition of the segmented copolymers on the degree of phase separation are clarified by the thermal- and mechanical properties. Figures 2-6 show the differences in thermal properties and monomer distribution of segmented co-polyesters with soft segment pre-polymer length of 2000 and hard segment pre-polymer lengths of 2000 (cap2000) and 3000 (cap3000) and 4000 (cap4000), respectively. Also, the properties of the random poly(dl-lactide -ε-caprolactone) prepared at 120 °C during 5 days are shown. The glass transition temperature (Tg) of the soft segment in cap3000 and cap4000 is higher than that in cap2000 with a similar monomer ratio (figure 2): the amorphous phase of cap3000 and cap4000 contains less amorphous PCL than that of cap2000, due to a better phase separation. Both are higher than the values of Tg of the random copolymers with similar monomer composition. Furthermore, the higher the ε-caprolactone content within a copolymer range with the same PCL length, the

lower the Tg will be, due to partly mixing of the amorphous PCL with the soft segment. In case of cap2000 and cap4000, the Tg of the copolymer with a low PCL content (23 % and 19% w/w, respectively) is almost as low as the Tg measured in the second run, where the copolymer is completely amorphous. In general, in the second DSC run, the Tg decreases with ε-caprolactone content and is independent of the monomer distribution (segmented or random).

The melting points of the hard segment (Tm) are shown in Figure 3. The melting point (maximum of melting peak) increases with ε-caprolactone content and is highest for the cap3000 series with a maximum value at a ε-caprolactone content of about 75%. A cap4000 copolymer with a caprolactone content of 67.4 % has a much higher melting point than the cap3000 copolymer with a similar monomer composition. This is the result of a better phase separation of the longest PCL segment. The melting points with the highest ε-caprolactone content within the cap3000 series are somewhat lower than expected, probably caused by incomplete phase separation. The melting temperatures of the segmented copolymers with a large ε-caprolactone content are only a little lower than those of the PCL pre-polymer (58-60 °C) and of PCL with Mn =80000, having a Mp of 63 °C. Melting points of the random copolymers are much lower (42-44 °C) than those of the segmented copolymers and are also much broader (the onset of the melting peak begins at 25-30 °C). This proves that there is a better phase separation in the segmented copolymers than in the random copolymers. In the second DSC run, melting temperatures of the segmented copolymers are lower (40-45°C) due to incomplete phase separation. Re-crystallization does not occur at the lowest ε-caprolactone contents: the cap4000 copolymers start to re-crystallize at a lower ε-caprolactone content than the cap3000 and cap2000 copolymers. Therefore, the annealing time must be long enough to obtain complete phase separation. Melting temperatures of the random copolymers are also much lower (38-40 °C) or they are absent in the second run. These results are comparable to those found in literature (Lemmouchi et.al., Hiljanen-Vainio et.al.)

Figure 4 shows the melting enthalpy (ΔH) of the three segmented copolymers and the random copolymer versus the ε-caprolactone content. The melting enthalpies of the cap3000 and cap4000 copolymers are largest and increase, both with the same trend, almost linearly with increasing ε-caprolactone content. A larger ε-caprolactone content leads to a larger melting enthalpy and therefore to a larger degree of crystallinity (as a reference, the melting enthalpy of the PCL pre-polymers is about 100 J/g).

The melting enthalpy of the random copolymers is not linearly dependent on the ε-caprolactone content. In fact, it is linearly related to the average monomer sequence length of ε-caprolactone, $\bar{L}_{Cap}$. Figure 5 shows this relationship for the random- and segmented copolymers. Clearly, the cap3000 and cap4000 copolymers show larger melting enthalpies than the cap2000 and the random copolymers, at a similar average ε-caprolactone sequence length. In figure 6 it is shown that within the cap2000, cap3000 and cap4000 series, $\bar{L}_{Cap}$ increases with ε-caprolactone content, the relation being independent of the PCL length. However, this is not the case for the random copolymers. The monomer distribution is determined by the polymerisation conditions. The random copolymers are all prepared at the same polymerisation time and -temperature, but with a different catalyst concentrations. A lower catalyst concentration results in longer monomer sequence lengths and therefore, more crystallization occurs. The segmented copolymers are prepared by mixing of two pre-polymers: the average ε-caprolactone sequence length can be increased by adding more of the PCL pre-polymer. By this method, the average sequence length of lactide does not change and will be constant within a copolymer series (not shown). This means that during the short time of chain-extending, no trans-esterification reaction occurs and the final polymer properties are only dependent on the pre-polymer properties.

Concerning the thermal properties, the segmented copolymers are more suitable for biomedical applications than the random copolymers. Depending on the type of application, the monomer ratio can be changed while

keeping the same thermal (and mechanical) properties simply by changing the length of the pre-polymers.

Mechanical properties

Mechanical properties of the segmented copolymers are dependent on the degree of phase separation and therefore on the degree of crystallinity. As an example, the stress strain behavior of the segmented co-polyesters with the PCL pre-polymer with Mn = 3000 is shown in figure 7. The stress at a certain degree of elongation (e.g 400%) increases with PCL content, so is the modulus. The tensile strength is also dependent on the amount of strain induced crystallization, which occurs when amorphous PCL starts to crystallize as a result of orientation. Figure 8 presents the relation between the initial modulus and the ε-caprolactone content: the modulus of the PCL3000 containing copolymer is higher than that of the PCL2000 containing copolymer with the same ε-caprolactone content, as a result of the higher degree of crystallinity (melting enthalpy) of the former. The modulus of the random copolymers is variable with the ε-caprolactone content and can be as high as those of the segmented copolymers. In fact, the modulus is related to the average monomer sequence length, $\bar{L}_{Cap}$, a property that can be altered by varying the polymerisation conditions. In general, the modulus is related to the average monomer sequence length, $\bar{L}_{Cap}$, in the same way as is the melting enthalpy as has been shown in figure 5. Although, from a mechanical point of view, the random copolymers can be as good as the segmented copolymers, the thermal properties are inferior to those of the segmented copolymers.

The modulus of the segmented co-polyesters can be much higher than those of amorphous, lactide rich copolymers (e.g. poly(dl-lactide-ε-caprolactone) with a 50:50 monomer ratio has an elastic modulus of 1-2 MPa). Therefore, segmented copolymers, even with a rather low ε-caprolactone content, can be processed into materials with a high modulus. For an application such as an artificial nerve guide for bridging long nerve gaps, a

modulus that is high enough to prevent compression of the nerve guide is required. This can be accomplished by using segmented co-polyesters.

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Claims

1. Biodegradable, phase separated copolymer, comprising blocks or segments of a soft prepolymer (A) having a Tg lower than 37°C; and blocks or segments of a hard polyester prepolymer (B) having a phase transition temperature of 40-100°C.

2. Copolymer according to claim 1, wherein prepolymer (A) comprises ester and/or carbonate groups, optionally in combination with polyethers.

3. Copolymer according to claim 2, wherein prepolymer (A) comprises reaction products of ester forming monomers selected from diols, dicarboxylic acids and hydroxycarboxylic acids.

4. Copolymer according to any of the previous claims, wherein prepolymer (A) comprises reaction products of cyclic monomers and/or non-cyclic monomers.

5. Copolymer according to claim 4, wherein said cyclic monomers are selected from glycolide, lactide, dioxanon, ε-caprolactone, δ-valerolactone and/or trimethylene carbonate.

6. Copolymer according to claim 4 or 5, wherein said non-cyclic monomers are selected from succinic acid, glutaric acid, adipic acid, lactic acid, glycolic acid, ethylene glycol, 1,4-butanediol and/or 1,6-hexanediol.

7. Copolymer according to claim 2-6, wherein said polyethers are selected from PEG (polyethylene glycol), PEG-PPG (polypropylene glycol), PTMG (polytetramethyleneether glycol) and combinations thereof.

8. Copolymer, according to any of the previous claims, in particular a copolymer having a random monomer distribution, wherein prepolymer (A) is prepared by a ring-opening polymerisation initiated by a diol or di-acid compound.

9. Copolymer according to any of the previous claims, wherein prepolymer (B) is prepared by a ring-opening polymerisation initiated by a diol or di-acid compound.

10. Copolymer according to any of the previous claims, wherein prepolymer (B) is based on ε-caprolactone, δ-valerolactone, lactide and/or glycolide.

11. Copolymer according to claim 10, wherein prepolymer (B) is poly-ε-caprolactone.

12. Copolymer according to claim 11, wherein prepolymer (B) has a Mn of larger than 1000, preferably larger than 2000, more preferably larger than 3000.

13. Copolymer according to claim 11 or 12 wherein the content of prepolymer (B) is 10-90 wt.% preferably 30-50 wt.%.

14. Copolymer according to any of the previous claims, having an intrinsic viscosity of at least 0.1 dl/g, and preferably between 1-4 dl/g.

15. Process for preparing a copolymer according to any of the previous claims, comprising a chain extension reaction of prepolymer (A) and prepolymer (B) in the presence of a suitable chain extender, whereby a randomly segmented or multi-block copolymer is obtained.

16. Process according to claim 16, wherein said chain extender is a difunctional aliphatic molecule.

17. Process according to claim 17, wherein said difunctional aliphatic molecule is a diisocyanate, preferably butanediisocyanate.

18. Process for preparing a copolymer according to any of the claims 1-14, comprising a coupling reaction, wherein one of the pre-polymers A or B is diol terminated while the other pre-polymer is di-carboxylic acid terminated, using a coupling agent.

19. Process according to claim 19, wherein the coupling agent is dicyclohexyl carbodiimide (DCC).

20. Process for preparing a copolymer according to any of the claims 1-14, comprising a coupling reaction, wherein prepolymer (A) is coupled to

prepolymer (B) by reacting prepolymer (A) with monomers which form prepolymer (B), whereby a tri-block copolymer is obtained.

21. Process for preparing a copolymer according to any of the claims 1-14, comprising a coupling reaction, wherein prepolymer (B) is coupled to prepolymer (A) by reacting pre-polymer (B) with monomers which form pre-polymer (A), whereby a tri-block copolymer is obtained.

22. Process for preparing a copolymer according to any of claims 1-14, comprising a chain extension reaction of a pre-polymer prepared according to the process in claim 20 and 21 in the presence of a suitable chain extender, whereby a multi-block copolymer is obtained.

23. Use of a copolymer according to claim 1-14 or the copolymer obtainable by the process of claim 15-22 as an implant or in drug delivery.

24. Sponge, implant, nerve guide, meniscus prosthesis, film, foil, sheet, membrane, plug or micro-spheres comprising a copolymer according to claim 1-15 or the copolymer obtainable by the process of claim 15-22.

25. Sponge according to claim 24 having a porosity of 50-99%.

(55)

Title: Biodegradable phase separated segmented/block co-polyesters

Abstract

The invention is directed to biodegradable, thermoplastic, phase separated segmented/block copolymers. The copolymers of the present invention find use in various biomedical applications as well as in pharmaceutical applications.

According to the invention a biodegradable, phase separated copolymer is provided, comprising blocks or segments of a soft prepolymer (A) having a Tg lower than 37°C; and blocks or segments of a hard polyester prepolymer (B) having a phase transition temperature of 40-100°C.